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Cumulative sum analysis of learning curve for video-assisted mini-laparotomy partial nephrectomy in renal cell carcinoma

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Abstract

Video-assisted mini-laparotomy surgery (VAMS), a hybrid of open and laparoscopic surgical techniques, is an important surgical approach in the field of partial nephrectomy. The learning curve for VAMS partial nephrectomy has not been studied to date; we therefore, evaluated this learning curve.

We prospectively evaluated 20 consecutive patients who underwent VAMS partial nephrectomy performed by a single surgeon (YEY) between March 2015 and December 2016. The learning curve was evaluated using the cumulative sum method. The measure of surgical performance was composed of 3 parameters (total operation time [Op time], warm ischemic time [WIT], and estimated blood loss [EBL]).

Among the 20 patients who underwent VAMS partial nephrectomy, the mean age was 54.6 years. The mean Op time and WIT were 172.5 and 28.8 minutes, respectively. The learning curve for the Op time, WIT, and EBL consisted of 3 unique phases: phase 1 (the first 7 cases), phase 2 (the next 5 to 7 cases), and phase 3 (all subsequent cases). Phase 1 represents the initial learning curve, and the phase 2 plateau represents the period of expert competency. Phase 3 represents when one is competent in VAMS partial nephrectomy.

The learning curve for VAMS partial nephrectomy is relatively short and after a learning curve of approximately 7 cases, the surgeon became familiar with VAMS partial nephrectomy; after 12 to 14 cases, the surgeon became competent in this procedure.

Abbreviations: ASA = American Society of Anesthesiologists, BMI = body mass index, BSA = body surface area, CUSUM = cumulative sum, EBL = estimated blood loss, LPN = laparoscopic partial nephrectomy, Op = operation, RALPN = robot-assisted laparoscopic partial nephrectomy, VAMS = video-assisted mini-laparotomy surgery, WIT = warm ischemic time.

Keywords: cumulative sum (CUSUM), learning curve, partial nephrectomy, video-assisted mini-laparotomy surgery (VAMS)

Editor: Vito Mancini.

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent was not required for the purposes of this study as it was based upon retrospective anonymous patient data and did not involve patient intervention or the use of human tissue samples.

The datasets can be requested upon corresponding author with the permission of Institutional Review Board of the Yonsei University Health System.

The authors declare that they have no conflicts of interest to declare.

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Medicine (2019) 98:17(e15367)

Received: 11 October 2018 / Received in final form: 11 February 2019 / Accepted: 31 March 2019

http://dx.doi.org/10.1097/MD.0000000000015367

1. Introduction

Innovations and advancements in surgical instrumentation and technology have improved surgical proficiency, and acquiring the ability to perform such techniques is considered important for healthcare providers. This acquisition and understanding of new surgical techniques is represented by a learning curve.[1] Assessment of healthcare quality has increased in importance in medical practice, and statistical process-control methods are used to monitor this quality.[2] The cumulative sum (CUSUM) technique, one of the methods developed to monitor the performance and quality of the industrial sector, was adopted by the medical field in the 1970s to analyze learning curves for surgical procedures.[3–4]

Video-assisted mini-laparotomy surgery (VAMS), a hybrid of laparoscopic and open surgical techniques, does not require gas insufflation and extracts an intact solid organ through a minimal incision.[5] Laparoscopic partial nephrectomy (LPN) is the traditional approach and standard treatment option for most small renal masses,[6–8] while robot-assisted laparoscopic partial nephrectomy (RALPN) has been introduced with the goal of reducing the learning curve for intracorporeal suturing, and facilitating renorrhaphy.[9] Several studies have reported learning curves for both LPN and RALPN[9–10]; however, no study has yet reported the learning curve for VAMS partial nephrectomy since VAMS has not been performed widely and it's awareness is low. We investigated the learning curve for VAMS partial nephrectomy using CUSUM methodology.

2. Materials and methods

This retrospective study was conducted via medical record review of patients at the Severance Hospital, Seoul, South Korea. The Institutional Review Board of the Yonsei University Health System approved the protocol for this study (project no: 4-2017-0457). The study included 20 consecutive VAMS partial nephrectomy surgery procedures performed between March 2015 and December 2016 by a single experienced urologist (YEY).

All procedures were performed using the VAMS technique, with the patient placed in the semilateral position. The operative space was the retroperitoneal space, and a piercing abdominal wall elevator, a piercing peritoneal retractor, and blades from an external self-retaining retractor system were used. A 6- to 7-cm transverse skin incision made 2 fingerbreadths superior to the level of umbilicus, beginning at the lateral border of the rectus abdominis and extending laterally to the costal margin (Fig. 1). A detailed description of the surgical technique has been provided elsewhere.[11] The operation time (Op time) was defined as the time from the first incision to that of the final closure. Demographic data were retrospectively retrieved, including patient age, gender, height, weight, body mass index (BMI), body surface area (BSA), American Society of Anesthesiologists (ASA) score, past history of hypertension and diabetes mellitus, and location of kidney cancer. Intraoperative parameters including Op time, warm ischemic time (WIT), and estimated blood loss (EBL) were analyzed as well as the patient's hospital length of stay. The RENAL nephrometry score is used to characterize a renal tumor based on tumor radius, endophyticity level, nearness to collecting system, and location (RENAL).[12] Computed tomography or magnetic resonance imaging images of renal tumors were independently reviewed by a urologist resident and a urologist without knowledge of each case and those cases with disagreements were reviewed by other urologist residents and urologists. For the parameters for surgical performance, Op time, WIT, and EBL were used. Laboratory test results obtained preoperatively, immediately after the procedure, and 1 day after the procedure were included.

2.1. CUSUM analysis

Learning curve provides mathematical representation of the learning process that takes place as operation repetition occurs and in our study, 3 indicators, Op time, WIT, and EBL were evaluated. For quantitative assessment of the learning curve, the CUSUM technique was used to analyze the 20 cases. The CUSUM is the running total of differences between the individual data points and the mean of all data points. Thus, CUSUM can be performed recursively.[1] The cases were ordered chronologically, from the earliest to the latest date of surgery. The Op time for each case is defined as x_i, and the mean Op time of all the cases is defined as μ. Therefore, the CUSUM at Op time n ($\mathrm{CUSUM}_{\mathrm{OTn}}$) is calculated as follows:

$$\mathrm{CUSUM}_{\mathrm{OTn}} = \sum_{i=1}^{n} xi - \mu$$

The $\mathrm{CUSUM}_{\mathrm{OT1}}$ of the first case was the difference between the Op time for the first case and the μ_{OT}. The $\mathrm{CUSUM}_{\mathrm{OT2}}$ of the second case was the previous case's $\mathrm{CUSUM}_{\mathrm{OT}\backslash}$ added to the difference between the Op time for the second case and μ_{OT}. This recursive process continued until the $\mathrm{CUSUM}_{\mathrm{OT}}$ for the last case was calculated. Similarly, additional parameters of surgical performance, WIT and EBL, were evaluated using CUSUM method.

Three phases were identified by the inflection point of the CUSUM curve. Phase 1 shows expected incline in CUSUM curve which is the initial learning curve, followed by a plateau (phase 2) which is the additional experience obtained leading the achievement of expert competence. Then there is decline in the plateau, which is the phase 3 being the post-learning period, as seen in typical learning curve studies.

2.2. Statistical analysis

The results are reported as mean (standard deviation) for continuous variables and as percentage values for categorical variables. For the comparison of phases 1, 2, and 3, analysis of variance was used to compare continuous variables and chi-square test or Fisher exact test for categorical variables. SPSS software version 23.0 (SPSS Inc, Chicago, IL) was used for statistical analyses. All statistical tests were 2-tailed, and a P-value $<.05$ was considered to indicate statistical significance.

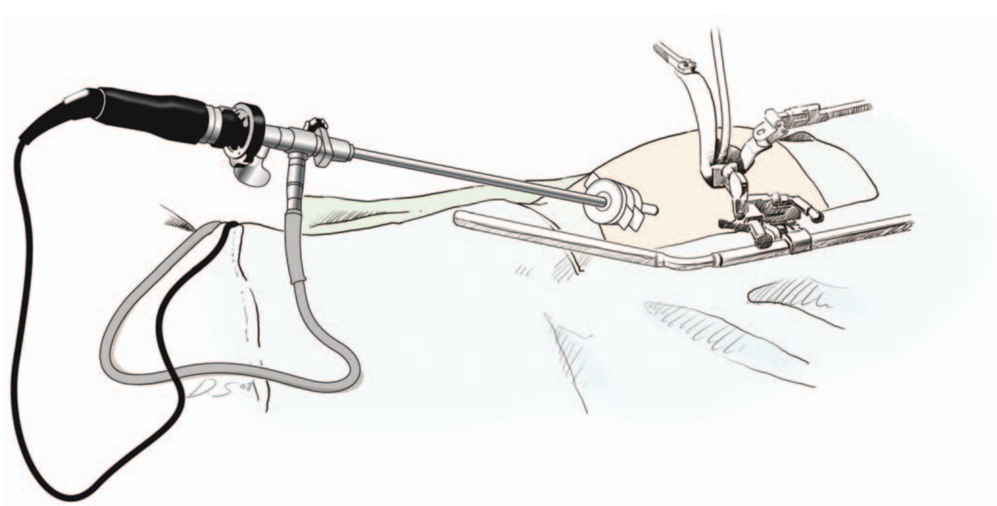

Figure 1. Operative setup for VAMS. VAMS = video-assisted mini-laparotomy surgery.

Table 1

Characteristics of the study population.

	Study population (n=20)
Patient characteristics	
Age, yr	54.6 (13.0)
Gender	
Male	15 (75.0%)
Female	5 (25.0%)
Height, cm	166.5 (6.9)
Weight, kg	66.6 (8.2)
BMI, kg/m^2	24.0 (2.1)
BSA, m^2	1.7 (0.1)
ASA score	
1	4 (20.0%)
2	9 (45.0%)
3	7 (35.0%)
HTN, n (%)	9 (45.0%)
DM, n (%)	5 (25.0%)
Kidney	
Right	8 (40.0%)
Left	12 (60.0%)
RENAL score, mean	8.8
Intraoperative parameters	
Op time, min	172.5 (41.3)
Warm ischemic time, min	28.8 (8.1)
EBL, cc	196.5 (209.1)
Postoperative outcomes	
Tumor size, cm	3.5 (0.9)
Pathology	
Clear cell	16 (80.0%)
Papillary	2 (10.0%)
Chromophobe	1 (5.0%)
Multilocular cystic	1 (5.0%)
LOS, d	5.9 (2.1)

Data are shown as mean (SD) or number of subjects (%).
ASA=American Society of Anesthesiologists, BMI=body mass index, BSA=body surface area, DM=diabetes mellitus, EBL=estimated blood loss, HTN=hypertension, LOS=length of stay, Op=operation.

3. Results

The baseline characteristics of the study population are presented in Table 1. The series consisted of 15 males (75.0%) and 5 females (25.0%) with a mean age of 54.6 years. Mean BMI and BSA were 24.0 kg/m^2 and 1.7 m^2, respectively. The median ASA score was 2. Nine patients (45.0%) had hypertension and 5 patients (25.0%) had diabetes mellitus. The tumor was located on the right side in 8 cases (40.0%). The mean Op time and WIT were 172.5 and 28.8 minutes, respectively. The mean EBL was 196.5 cc, with a mean tumor size of 3.5 cm. Clear cell type accounted for 16 cases (80.0%). Preoperative and postoperative serum creatinine levels were 0.9 and 1.1 mg/dL, respectively, with statistical significant difference ($P<.001$).

The Op times were plotted in chronological case order (Fig. 2). The $CUSUM_{OT}$ learning curve was best modeled as a second-order polynomial with the following equation: $CUSUM_{OT}$ (in minutes) $=-1.24\times \text{case number}^2+19.002\times \text{case number}+62.238$, which had high R^2 value of 0.6098. The $CUSUM_{OT}$ learning curve consisted of 3 unique phases: phase 1 (the first 7 cases), phase 2 (the next 5 cases), and phase 3 (the final 8 cases) (Fig. 2). Comparisons between the 3 phases identified by $CUSUM_{OT}$ analysis are presented in Tables 2 and 3. There were no significant differences between the different phases in terms of patient age, gender, height, weight, BMI, BSA, ASA score, hypertension, diabetes mellitus, RENAL score, location of tumor, and tumor size. Op times were decreased in phase 2 ($P=.073$) and phase 3 ($P=.049$) compared with phase 1. WITs in phase 2 and 3 were significantly shorter than those in phase 1 ($P=.048$). EBL was significantly smaller in phase 3 than in phase 1 ($P=.049$); however, there was no significant difference in EBL between phase 2 and phase 1.

Figures 3 and 4 shows the CUSUM learning curves of WIT and EBL, respectively. Both of the curves consisted of 3 unique phases with initial 7 cases of phase 1, and additional 7 cases (WIT) and 5 cases (EBL) in phase 2.

4. Discussion

This is the first study to investigate the learning curve for VAMS partial nephrectomy. The learning curve is a graphic representation showing the relationship between the surgeon's competence and number of cases performed. The focus of this study was to evaluate the surgeon's operative competency based on 3 parameters, Op time, WIT, and EBL, and to divide the learning curve into phases that correlate with the level of competency achieved. We analyzed the learning curve using the CUSUM technique. Statistical process-control methods such as the CUSUM technique were first used in pediatric cardiac surgery[11] and are still used in monitoring the performance of cardiac surgeons and the outcome of surgery.[13]

Previous studies have reported learning curves for RALPN and LPN.[9–10,14] LPN, which is a challenging procedure, requires considerable skill and expertise in techniques such as intracorporeal suturing with minimal ischemic times.[15] Even for experienced laparoscopic surgeons, the learning curve (in terms of Op time) for LPN is in the range of 100 to 150 cases.[16] The introduction of robotic systems into partial nephrectomy decreased the difficulty of intracorporeal suturing because of the 6 degrees of freedom at the distal end of the instruments, magnified vision, scaled-down movement, and decreased tremor.[17–18] For surgeons already experienced with LPN, the learning curve for RALPN is 16 cases, based on overall operative time.[19]

In the present study, phase 1, the initial learning curve phase, shows that after 7 cases, a surgeon with no prior experience in partial nephrectomy could reach the learning phase in every parameters of surgical performance. Over an additional 5 to 7 cases, comprising phase 2, the additional experience obtained led to the achievement of expert competence. Compared with the learning curves for LPN and RALPN, VAMS partial nephrectomy has a shorter learning curve. This might be due to several reasons. First, VAMS is a hybrid of open and laparoscopic surgical technique. Whereas LPN and RALPN use needle drivers that a novice may find difficult to handle, VAMS uses tools that are typically used in open surgery, and are therefore familiar to most surgeons who have basic training in open surgery. Second, VAMS uses a telescope that has a magnified view and an internal light source. This enables the surgeon to have clear view of the operative field. Moreover, use of the telescope enables recording of the procedure, which can then be used as an educational tool. The surgeon in our study also reviewed the recordings for the educational purposes before the first surgery. In addition, surgeons who are not familiar with laparoscopy can evaluate the differences between the real operative field, and the view of the operative field through the telescope. This is extremely

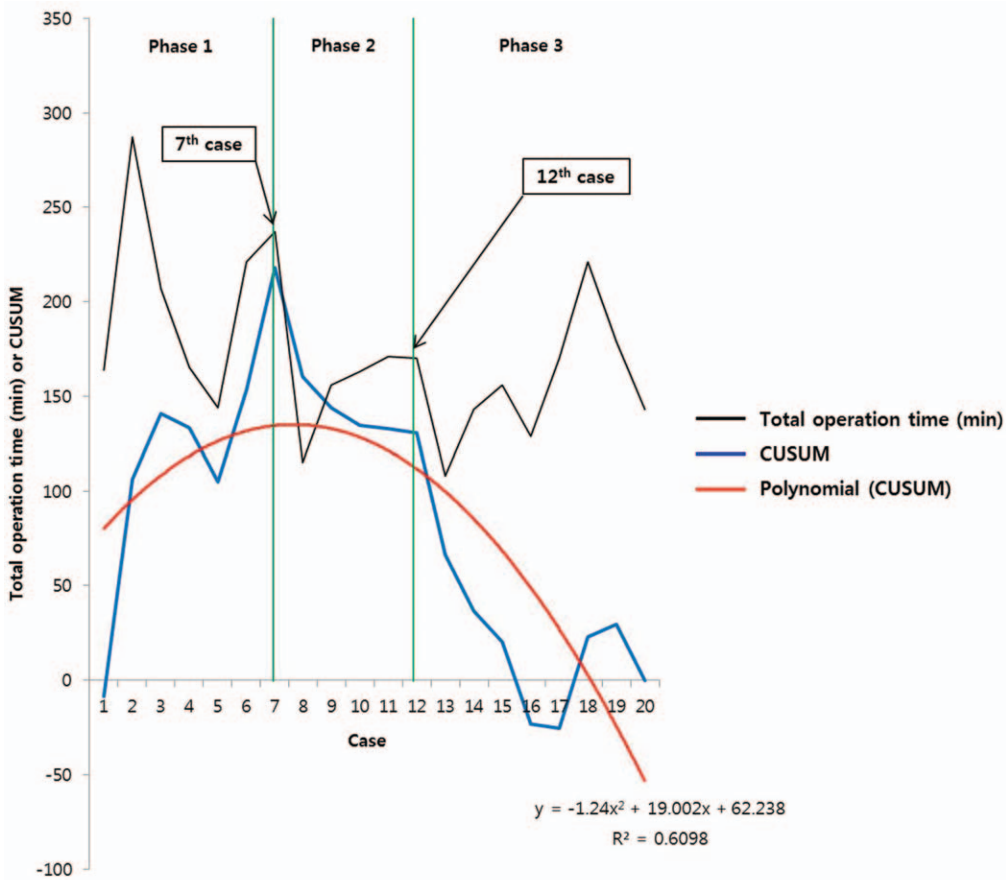

Figure 2. Total operation time (black) and $CUSUM_{OT}$ (blue line) plotted against case number; the red line represents the best fit curve for the plot, which is a second-order polynomial with the equation $CUSUM_{OT} = -1.24 \times \text{case number}^2 + 19.002 \times \text{case number} + 62.238$ ($R^2 = 0.6098$). Three phases were identified based on total operation time in terms of the CUSUM learning curve. CUSUM = cumulative sum.

Table 2

Interphase comparisons of patient characteristics and other parameters.

	Phase 1 (0–7, n=7)	Phase 2 (8–12, n=5)	Phase 3 (13–20, n=8)	*P*-value
Patient characteristics				
Age, yr	50.3 (15.7)	58.2 (13.6)	56.0 (10.7)	.562
Gender				
Male	4 (57.1%)	5 (100%)	6 (75.0%)	.283
Female	3 (42.9%)	0 (0.0%)	2 (25.0%)	
Height, cm	163.8 (7.8)	168.6 (5.5)	167.5 (6.9)	.449
Weight, kg	66.4 (9.7)	66.1 (9.3)	67.0 (7.2)	.981
BMI, kg/m^2	24.7 (2.4)	23.2 (2.9)	23.8 (0.9)	.504
BSA, m^2	1.7 (0.2)	1.8 (0.1)	1.8 (0.1)	.87
ASA score				
1	1 (14.3%)	1 (20.0%)	2 (25.0%)	.492
2	5 (71.4%)	1 (20.0%)	3 (37.5%)	
3	1 (14.3%)	3 (60.0%)	3 (37.5%)	
HTN, n (%)	3 (42.9%)	2 (40.0%)	4 (50.0%)	1.000
DM, n (%)	3 (42.9%)	1 (20.0%)	1 (12.5%)	.449
Kidney				
Right	4 (57.1%)	1 (20.0%)	3 (37.5%)	.537
Left	3 (42.9%)	4 (80.0%)	5 (62.5%)	
RENAL score, mean	8.9 (1.7)	8.2 (0.8)	9.0 (1.3)	.580
Intraoperative parameters				
Op time, min	203.6 (50.0)	155.0 (23.2)	156.1 (34.5)	.054
WIT, min	34.4 (9.0)	24.0 (2.9)	26.8 (6.9)	.048
EBL, cc	360.0 (282.0)	126.0 (91.5)	97.5 (65.4)	.120
Postoperative outcomes				
Tumor size, cm	3.3 (1.1)	3.5 (0.5)	3.6 (1.0)	.834
Pathology				
Clear cell	7 (100.0%)	2 (40.0%)	7 (87.5%)	.017
Papillary	0 (0.0%)	2 (40.0%)	0 (0.0%)	
Chromophobe	0 (0.0%)	1 (20.0%)	0 (0.0%)	
Multilocular cystic	0 (0.0%)	0 (0.0%)	1 (12.5%)	
LOS, d	6.4 (2.1)	6.4 (3.1)	5.1 (1.2)	.426

Data are shown as mean (SD) or number of subjects (%).

ASA = American Society of Anesthesiologists, BMI = body mass index, BSA = body surface area, DM = diabetes mellitus, EBL = estimated blood loss, HTN = hypertension, LOS = length of stay, Op = operation.

P-value calculated using ANOVA for continuous variables and chi-square test or Fisher exact test for categorical variables.

Table 3

Laboratory measurements taken before the operation, immediately after the operation, and 1 d after the operation.

	Phase 1 (0–7, n=7)	Phase 2 (8–12, n=5)	Phase 3 (13–20, n=8)	*P*-value
Pre-Op Lab				
WBC, /μL	8127.1 (1823.0)	7380.0 (1783.6)	6586.3 (1481.7)	.236
RBC, 10^6/μL	4.5 (0.4)	4.6 (0.7)	4.7 (0.6)	.758
Hb, g/dL	14.1 (1.3)	14.5 (1.7)	14.7 (2.2)	.828
Hct (%)	42.2 (3.9)	42.7 (4.7)	43.7 (5.9)	.829
Ca, mg/dL	9.5 (0.3)	9.2 (0.5)	9.3 (0.5)	.541
P, mg/dL	3.6 (0.5)	3.7 (0.6)	3.3 (0.5)	.302
Glucose, mg/dL	121.3 (48.4)	135.8 (68.2)	106.6 (17.5)	.534
BUN, mg/dL	16.9 (7.0)	14.6 (2.9)	17.6 (4.8)	.627
Creatinine, mg/dL	0.8 (0.2)	1.0 (0.1)	0.9 (0.2)	.136
eGFR (MDRD), mL/min/1.73 m^2	100.0 (23.5)	80.5 (15.1)	85.6 (18.9)	.223
Uric acid, mg/dL	5.1 (1.3)	6.5 (0.5)	5.1 (1.4)	.101
Cholesterol, mg/dL	184.4 (38.3)	178.8 (62.3)	187.9 (27.2)	.930
AST, IU/L	16.9 (4.0)	29.4 (8.0)	21.3 (3.5)	.002
ALT, IU/L	21.4 (13.3)	32.8 (10.9)	22.6 (11.3)	.245
Immediate Post-Op Lab				
WBC, /μL	15438.6 (3094.5)	13780.0 (3790.8)	14526.3 (3732.0)	.723
RBC, 10^6/μL	3.8 (0.4)	4.2 (0.6)	4.1 (0.7)	.556
Hb, g/dL	11.9 (1.1)	12.8 (1.7)	13.0 (2.4)	.523
Hct (%)	35.4 (3.0)	39.2 (4.3)	38.9 (6.9)	.359
Ca, mg/dL	7.6 (0.4)	8.2 (0.3)	7.7 (0.6)	.111
P, mg/dL	3.0 (0.4)	3.1 (1.0)	3.1 (0.3)	.046
Glucose, mg/dL	154.3 (30.8)	128.2 (30.0)	152.8 (47.5)	.460
BUN, mg/dL	15.1 (5.2)	17.8 (5.3)	13.9 (3.8)	.373
Creatinine, mg/dL	0.8 (0.1)	1.1 (0.1)	1.0 (0.2)	.043
eGFR (MDRD), mL/min/1.73 m^2	90.6 (19.0)	67.8 (6.1)	77.6 (12.8)	.024
Uric acid, mg/dL	4.4 (0.9)	5.8 (0.8)	4.7 (1.1)	.059
Cholesterol, mg/dL	132.7 (40.1)	159.6 (57.1)	160.3 (33.4)	.428
AST, IU/L	18.7 (3.4)	30.4 (11.1)	26.6 (24.9)	.478
ALT, IU/L	13.7 (4.6)	31.8 (10.6)	22.1 (14.0)	.034
Post-Op Lab				
WBC, /μL	12164.3 (1971.6)	10360.0 (2778.7)	10699.0 (2553.9)	.383
RBC, 10^6/μL	3.8 (0.4)	4.0 (0.7)	4.0 (0.4)	.590
Hb, g/dL	11.6 (1.1)	12.6 (1.9)	12.5 (1.2)	.352
Hct (%)	34.7 (3.1)	37.6 (5.5)	37.6 (3.7)	.329
Ca, mg/dL	7.9 (0.3)	8.3 (0.4)	7.8 (0.6)	.259
P, mg/dL	3.2 (0.4)	3.7 (0.3)	3.3 (0.7)	.016
Glucose, mg/dL	159.4 (47.4)	151.6 (40.3)	131.8 (54.8)	.545
BUN, mg/dL	19.5 (7.3)	20.6 (5.2)	16.3 (2.8)	.018
Creatinine, mg/dL	1.0 (0.2)	1.3 (0.1)	1.1 (0.3)	.136
eGFR (MDRD), mL/min/1.73 m^2	73.8 (16.9)	59.2 (7.6)	69.9 (17.1)	.277
Uric acid, mg/dL	4.4 (1.0)	5.2 (0.7)	4.6 (1.3)	.454
Cholesterol, mg/dL	140.0 (40.7)	163.0 (61.6)	152.5 (34.5)	.690
AST, IU/L	24.1 (5.6)	33.2 (4.3)	28.6 (14.5)	.331
ALT, IU/L	16.0 (4.8)	32.2 (8.9)	23.0 (13.1)	.039

Data are shown as mean (SD).

ALT=alanine transaminase, AST=aspartate transaminase, BUN=blood urea nitrogen, Ca=calcium, Cr=creatinine, eGFR=estimated glomerular filtration rate, Hb=hemoglobin, Hct=hematocrit, HDL-C=high-density lipoprotein cholesterol, LDL-C=low-density lipoprotein cholesterol, MDRD=modification of diet in renal disease, P=phosphorus, RBC=red blood cell, TC=total cholesterol, TG=triglyceride, WBC=white blood cell.

P-value calculated using ANOVA.

important, because open surgical techniques do not use the telescope and therefore the surgeon may be unfamiliar with this view. In this way, the VAMS technique is not only a surgical tool itself, but also an educational tool that enables the surgeon to become familiar with laparoscopy. Third, VAMS uses an extraperitoneal approach, which poses no risk of bowel injury and has low morbidity. The surgeon can freely perform the surgery without considering bowel injury, and there is no need to consider adhesiolysis for patients with bowel adhesions. Fourth, VAMS is cost-effective surgery which does not require expensive equipment such as LPN and RALPN. The tools used in VAMS is not expensive and most of the tools are reusable.

VAMS has not been performed widely in partial nephrectomy where renal masses are small; however, it has several advantages. First, by getting real vision of the vascular structure, even when the vascular structure is complex, surgeons could isolate renal artery and vein more intuitively through direction vision. Second,

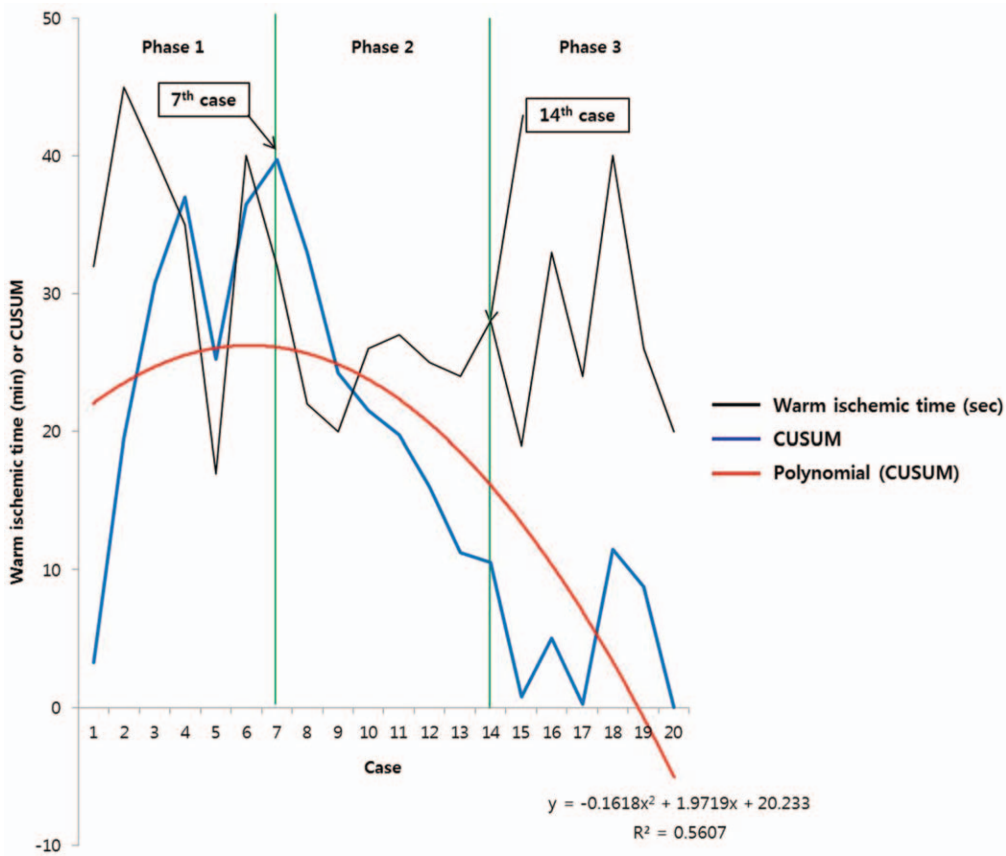

Figure 3. Warm ischemic time (black) and $CUSUM_{WIT}$ (blue line) plotted against case number; the red line represents the best fit curve for the plot, which is a second-order polynomial with the equation $CUSUM_{WIT} = -0.1618 \times$ case number$^2 + 1.9719 \times$ case number $+ 20.233$ ($R^2 = 0.5607$). Three phases were identified based on warm ischemic time in terms of the CUSUM learning curve. CUSUM = cumulative sum.

especially if the mass is located at hilar, it is easier to isolate the mass through using both the direct and endoscopic visions. Third, VAMS could be performed regardless of the tumor location. Fourth, retroperitoneal approach performed in VAMS minimizes unnecessary dissection.

We annually perform about 80 cases of RALPN or LPN. Although we prefer robot compared to laparoscopic methods, it depends on financial status of the patients since robot surgeries are not financially supported in Korean national medical insurance system. We have performed open or VAMS partial nephrectomy in cases where difficulty is expected or patients with single kidney. Recently, in most cases, VAMS has replaced open methods due to the many advantages mentioned above.

As expected, the total Op time significantly decreased after phase 1, and the WIT was shorter and EBL was smaller in phases 2 and 3 than in phase 1. This is probably due to the increasing competence of the surgeon in the VAMS technique. The mean WIT of LPN was 27.6 minutes. Although no specific methods were used to reduce case selection bias, the tumor sizes were not different between phases, suggesting that no specific phase contained cases that were particularly technically challenging. Moreover, patient characteristics such as BMI and BSA were not different between the phases. The RENAL nephrometry score also showed no differences between phases showing that there was no selection of easier cases at the start of the learning curve which results in selection bias. The procedure on kidney results in significant decrease in kidney function immediately after the operation due to the damage during the operation; however, it was recovered after certain period of time. This similar trend was also observed in LPN and RALPN.[20,21]

This study has several limitations. First, this was limited to a single-surgeon experience. Further studies including multiple surgeons in different training experiences would verify the learning curve results from our study. Second, although there were no differences in cases between different phases in our study, selection bias in the cases, if present, could have affected the learning curve for VAMS partial nephrectomy.

VAMS has advantages in partial nephrectomy by incorporating not only laparoscopic but also open surgical techniques where a surgeon could achieve expert competence with comparatively less time than other techniques. The reason that VAMS has not been widely used is that not many surgeons perform VAMS and its awareness is low. Therefore, we believe that this study will increase the interests in this surgeon friendly surgical approaches and increase the use of VAMS in partial nephrectomy which are considered as one of the sophisticated urological surgeries.

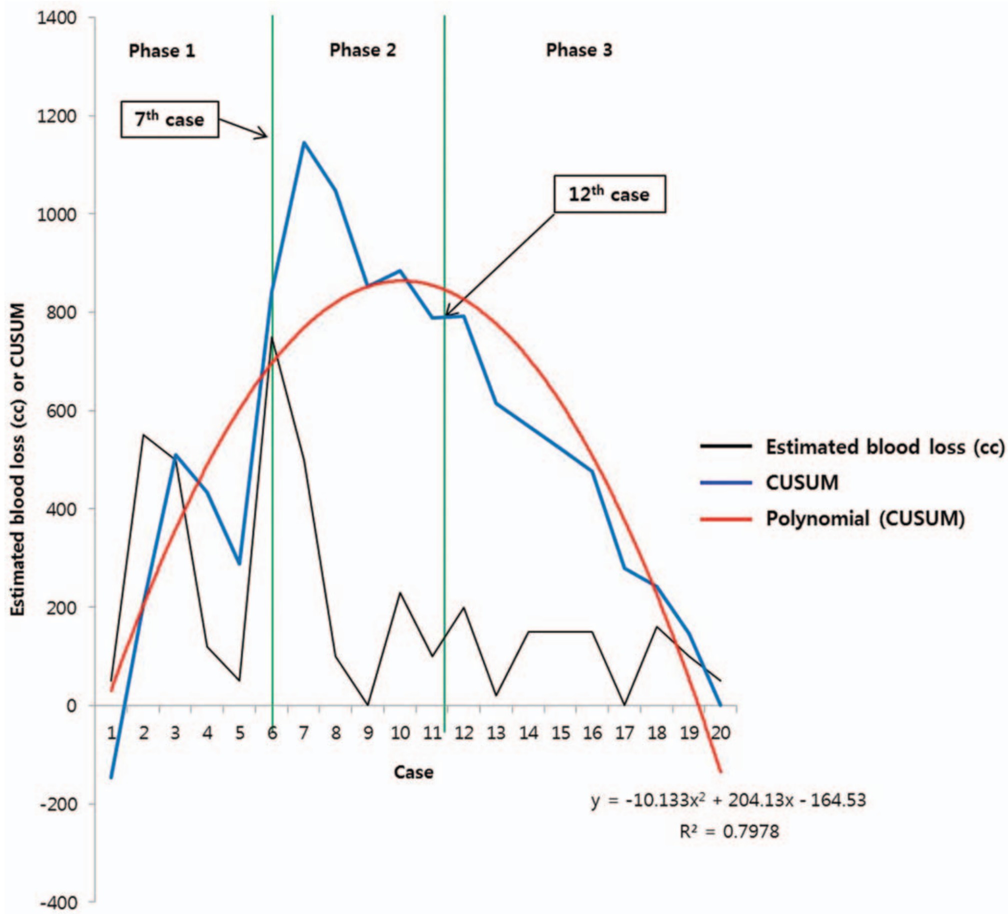

Figure 4. Estimated blood loss (black) and $CUSUM_{EBL}$ (blue line) plotted against case number; the red line represents the best fit curve for the plot, which is a second-order polynomial with the equation $CUSUM_{EBL} = -10.133 \times \text{case number}^2 + 204.13 \times \text{case number} - 164.53$ ($R^2 = 0.7978$). Three phases were identified based on estimated blood loss in terms of the CUSUM learning curve. CUSUM = cumulative sum.

5. Conclusions

This study identified 3 unique phases of the learning curve for VAMS partial nephrectomy using CUSUM analysis, showing that after 12 cases, a surgeon can achieve expert competence, with optimized WIT, total Op time, and EBL.

Author contributions

Conceptualization: Jee Soo Park.
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